FORMATION OF THE CRYSTALLINE LUNAR SPHERULES. Steven J. K. Symes. University of Arkansas, Fayetteville, AR 72701, Present Address: SN4, Planetary Science Branch, NASA Johnson Space Center, Houston, TX 77058.

Apollo 14 breccias contain abundant crystalline spherules that appear to be the result of impact melting and crystallization during free-flight. Their bulk compositions are quite different from the local regolith in which they were found and are clearly exotic to the site. The Imbrium impact is a likely source for these objects since long flight times are required for crystallization to be complete before re-impacting the surface.

The crystalline lunar spherules (CLS) found in Apollo 14 breccias 14315 and 14318 have been classified into 4 types based on texture and cathodoluminescence properties [1]. This study examines the textures and bulk compositions of the two dominant types (X and Y) in an effort to understand their formation conditions. An important constraint on their formation is the development of textures consistent with cooling much slower than free-flight through a vacuum would produce. This suggests an impact large enough to produce considerable gas and dust which could slow cooling rates.

CLS Textures and Compositions

The type X CLS show a wide diversity of plagioclase crystal sizes and morphologies. These objects are predominantly very fine-grained imparting a mostly granular texture. Importantly however, they often contain a few larger plagioclase crystals with highly irregular boundaries that do not appear to have been totally melted. The X objects often possess a full or partial thin, opaque rim. The type Y objects generally consist of acicular plagioclase crystals with sharp edges or euhedral lathes that interlock in a fretwork typical of intersertal textures. The interstitial material comprises fine-grained, near euhedral plagioclase crystals, pyroxene, olivine, and aluminum-rich glass. Most crystallization appears to have occurred randomly (there is no indication of the plagioclase nucleating perpendicular to the surface) and is consistent with rapid cooling from high temperature. The Y objects sometimes show a thin opaque rim.

The mineralogies of type X and type Y CLS are dominated by plagioclase, with only minor amounts of pyroxene, olivine, and rare opaques. Their bulk compositions are shown in Table 1. Plagioclase compositions in the type Y CLS are An_{95-85} while the mesostases are more mafic (12-20 wt% FeO and 5-21 wt% MgO). Feldspar in the type Y objects have compositions comparable to previous analyses of feldspar in similar lunar objects [2] and suggest derivation from a source region rich in anorthositic material. The phases in type X CLS could not be analyzed because of their fine-grained textures, but their bulk compositions are indistinguishable from those of type Y (Table 1) and clearly derive from a similar region.

Table 1. Bulk compositions (wt%) for all analyzed Type X and Type Y objects.

Oxide	Type X	Type Y
SiO_2	44.85	45.50
TiO_2	0.25	0.22
Al_2O_3	25.58	25.13
Cr_2O_3	0.17	0.13
FeO	6.40	6.04
MnO	0.09	0.08
MgO	5.28	5.49
CaO	13.96	13.66
Na_2O	0.54	0.70
K_2O	0.23	0.22
P_2O_5	0.09	0.11
Total	**97.43**	**97.30**

Formation of the CLS

The significant differences in the textures of these two types of CLS, despite near identical bulk compositions, are best understood in terms of differences in nucleation and subsequent crystal growth. Several dynamic crystallization studies have shown the importance of the density and distribution of crystallization nuclei in determining final textures (*e.g.*, [3-5]).

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These studies demonstrate that widely divergent textures on a 2-3 mm scale can be obtained simply by varying the pre-cooling melt history which affects the survival and distribution of heterogeneous nuclei. Further, it was found that experimental charges with 14310 compositions (not greatly different from the current X and Y compositions) formed porphyritic textures only when cooled from a nearly complete liquid [5]. The absence of porphyritic textures among any of the CLS suggests that they did not cool from a complete melt, placing constraints on the melt time and/or temperature.

The small size, and thus high numbers, of plagioclase crystals in the type X objects suggests that they experienced relatively low degrees of melting such that many crystallization nuclei survived and allowed small crystals to grow immediately upon cooling. The presence of fairly large (~50 μm) unmelted plagioclase crystals is consistent with low peak temperatures. For type Y objects, the acicular needles of plagioclase are indicative of rapid crystal growth suggesting crystallization from a more supercooled state resulting from higher degrees of melting and destruction of more nuclei.

The degree of supercooling a melt experiences before crystallization proceeds is essentially determined by the degree of melting (influenced by peak temperature and duration of high temperature phase). As the degree of melting is increased, more nuclei are destroyed such that crystallization is forced to proceed on ever smaller nuclei and ultimately, embryos. When nucleation does finally take place, crystal growth is rapid and non-equilibrium crystal forms result. These considerations suggest that type Y CLS experienced higher degrees of melting than type X objects and thus may have originated closer to the point of impact where kinetic energy transfer to the target is greatest (Fig. 1).

Conclusions

The crystalline lunar spherules are impact-generated melt spherules that crystallized during free-flight. It takes major impacts on the moon to produce enough hot gas and dust to insulate the spherules and the long ballistic flight times that are necessary to create CLS. Smaller impacts only produce impact glasses and agglutinates which are so common on the lunar surface since so many different impact sizes can create them.

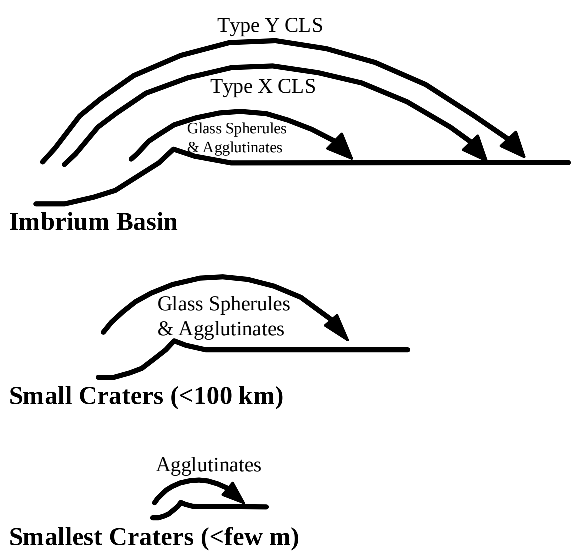

Fig. 1. Production of CLS, glass spherules, and/or agglutinates is controlled by the size of the impact.

References. [1] Symes *et al.* (1996) *MAPS*, submitted. [2] Kurat *et al.* (1974) *Geochim. Cosmochim.* Acta **38**, 1133-1146. [3] Lofgren G. E. (1983) *J. of Petrology*, 229-255. [4] Hewins R. H. (1988) in *Meteorites and the Early Solar System*, 660-679. [5] Lofgren G. E. (1977) *Proc. Lunar Sci. Conf. 8th*, 2079-2095.